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Claims

[c1] A method for closing exposed pores in a porous dielectric layer comprising:
providing a low-k porous dielectric layer having at least one exposed pore with a first reactant therein;
providing a second reactant into a mouth region of said at least one exposed pore while simultaneously outgassing said first reactant toward said mouth region;
generating an in-situ chemical reaction at said mouth region of said at least one exposed pore by contacting said second reactant with said outgassed first reactant; and
forming a pore-closing layer across said mouth region via said in-situ chemical reaction to transform said at least one exposed pore to at least one closed pore having porosity.

[c2] The method of claim 1 wherein said low-k porous dielectric layer comprises a dielectric material selected from the group consisting of an organic low-k porous dielectric material, an inorganic low-k porous dielectric material and an organic-inorganic low-k porous dielectric material.

[c3] The method of claim 1 wherein said low-k porous dielectric layer comprises a patterned low-k porous dielectric layer, said at least one exposed pore residing within an opening of said patterned low-k porous dielectric layer.

[c4] The method of claim 1 wherein said low-k porous dielectric layer is a spin-on low-k porous dielectric layer, said first reactant comprises residual volatile by-product porogen fragments of said spin-on porous dielectric layer residing within said at least one exposed pore.

[c5] The method of claim 4 further comprising the steps of:
generating said in-situ chemical reaction at said mouth region of said at least one exposed pore by contact between said reactant and said outgassed first reactant;
forming said pore-closing layer across said mouth region via said in-situ chemical reaction to transform said at least one exposed pore to at least one closed pore having porosity; and
allowing said in-situ chemical reaction occur for a time sufficient to allow said pore-closing layer grow out laterally from said at least one closed pore to form a liner layer on exposed surfaces of said low-k porous dielectric layer.

[c6] The method of claim 1 wherein said first reactant is provided within said at least one exposed pore by providing said first reactant over said porous dielectric layer for a time sufficient to allow said first reactant absorb within said at least one exposed pore.

[c7] The method of claim 6 further including removing any residual first reactant molecules provided on said porous dielectric layer prior to providing said second reactant into said mouth region of said at least one exposed pore.

[c8] The method of claim 6 further comprising the steps of:
depositing said first reactant over said porous dielectric layer for said time sufficient to allow said first reactant absorb within said at least one exposed pore and adsorb onto exposed surfaces of said low-k porous dielectric layer;
providing said second reactant into said mouth region of said at least one exposed pore while said first reactant is simultaneously outgassed toward said mouth region;
contacting said second reactant with said outgassed first reactant at said mouth region;
contacting said second reactant with said adsorbed first reactant on said exposed surfaces of said low-k porous dielectric layer;
generating said in-situ chemical reaction at said mouth

region by contact between said second reactant and said outgassed first reactant and at said exposed surfaces of said low-k porous dielectric layer by contact between said second reactant and said adsorbed first reactant;
forming said pore-closing layer across said mouth region via said in-situ chemical reaction to transform said at least one exposed pore to said at least one closed pore having porosity; and
forming a liner layer on said exposed surfaces of said low-k porous dielectric layer via said in-situ chemical reaction.

[c9] The method of claim 1 wherein said second reactant is provided into said mouth region of said at least one exposed pore by a chemical vapor deposition process.

[c10] The method of claim 1 wherein said low-k porous dielectric layer is immersed into a bath solution for providing said second reactant into said mouth region of said at least one exposed pore.

[c11] The method of claim 1 wherein said first reactant is selected from the group consisting of an oxygen-containing reactant, a carbon-containing reactant, ammonia, and TEOS.

[c12] The method of claim 1 wherein said second reactant is

selected from the group consisting of a silane-containing plasma, a TiN plasma in the absence of any NH_3 flow, and an acidic bath solution.

[c13] The method of claim 1 further including pre-treating said porous dielectric layer to increase hydrophilicity of said at least one exposed pore.

[c14] The method of claim 1 wherein said pore-closing layer has a thickness ranging from about 2nm to about 20nm inside and across said mouth region of said at least one closed pore.

[c15] A method for closing exposed pores in a porous dielectric layer prior to metallization comprising:
providing a substrate;
forming a low-k porous dielectric layer having a plurality of closed pores over said substrate;
patterning said low-k porous dielectric layer to form openings therein whereby selected ones of said closed pores are transformed to exposed pores within said openings;
providing a first reactant within said exposed pores in said openings of said low-k porous dielectric layer;
providing a second reactant into said openings in said low-k porous dielectric layer, said second reactant at least being introduced into a mouth region of each said

exposed pore while simultaneously outgassing said first reactant toward said mouth region;

generating an in-situ chemical reaction at least at said mouth region of each of said exposed pore by contacting said second reactant with said outgassed first reactant; and

forming a pore-closing layer across said mouth region via said in-situ chemical reaction to transform said exposed pores to closed pores.

[c16] The method of claim 15 further comprising:

adsorbing said first reactant onto exposed surfaces of said low-k porous dielectric layer within said openings;

providing said second reactant into said openings;

contacting said second reactant with said outgassed first reactant at said mouth region and with said adsorbed first reactant;

generating said in-situ chemical reaction at said mouth region and at said exposed surfaces of said low-k porous dielectric layer within said openings by contacting said second reactant with said outgassed and adsorbed first reactant; and

forming said pore-closing layer across said mouth regions and a bottomless liner layer within said openings on said exposed surfaces of said low-k porous dielectric layer via said in-situ chemical reaction.

[c17] The method of claim 15 wherein said low-k porous dielectric layer is a spin-on low-k porous dielectric layer, said first reactant comprises residual volatile by-product porogen fragments of said spin-on porous dielectric layer residing within said at least one exposed pore.

[c18] The method of claim 15 wherein said first reactant is provided within said at least one exposed pore by providing said first reactant over said porous dielectric layer for a time sufficient to allow said first reactant absorb within said at least one exposed pore.

[c19] A semiconductor structure comprising:
a substrate;
a patterned low-k porous dielectric layer on said substrate, said patterned low-k porous dielectric layer having at least one opening therein;
at least one closed pore within said opening having a pore-closing layer at a site-specific location across a mouth region of said closed pore, said pore-closing layer comprising a product of an in-situ chemical reaction at said mouth region between a second reactant and an outgassed first reactant; and
a metallization layer filling said at least one opening in said patterned low-k porous dielectric layer.

[c20] The semiconductor of claim 19 further including a bottomless liner layer on sidewalls of said at least one opening within said low-k porous dielectric layer, said bottomless liner layer comprising a material of said pore-closing dielectric layer.